MECHANICAL PROPERTIES OF IRON DOPED BISMUTH MICROWIRES IN GLASS ISOLATION

M. Dyntu, D. Meglei, S. Donu, and A. Rusu

Institute of Electronic Engineering and Industrial Technologies, Academy of Sciences of Moldova, 3/3, Academiei str., MD-2028, Chisinau, Republic of Moldova
(Received 3 November 2008)

Abstract

The mechanical properties of iron doped bismuth microwires by the breaking and flexing test methods were studied and the structural defect morphology, in combination with chemical reagent attack, was analyzed.

The analysis of experimental data permits us to conclude that iron forms microscopic inclusions in the bismuth matrix, leading to the breaking strength increase and the flexing strength diminution in comparison with the microwires of pure bismuth.

Introduction

Lately, the investigations have been carried out regarding the mechanical properties of materials with low dimensions (microns). The investigations are imposed by the field engineering that requires the new materials with adequate mechanical properties: high elasticity and durability. One of the directions that permit the improvement of these characteristics is the fabrication of composite materials from metals or from thermoelectric and ferromagnetic mixtures doped by impurities, such as microwires with micron dimensions in glass isolation [1].

This aspect of the problem imposes the intensive investigations undertaken for the elaboration of technologies accessible on large scale and competitive regarding the quality of obtained microwires, including the mechanical strength.

Experimental results and discussion

The main problems examined in this paper are connected with determination of mechanical properties, carried out by the flexion and breaking deformation and microscopic study of the morphology of structural defects of glass-isolated bismuth microwires doped with iron concentration up to ~10, ~20, ~30, and ~40 at % Fe in initial ingots.

The value of strength (σ) at breaking deformation of glass isolated microwires was measured by the ratio of applied force (P) and the cross-sectional area (s) of microwire, $\sigma = P/s = P/\pi r^2$, (kg/mm^2) [2].

The flexing strength, as a criterion of elasticity, was determined by the flexion critical radius, which, in accordance to the utilized method, was calculated as the ratio of length (l) of the microwire exposed to flexion and the flexure angle (φ), $R = 1/2\sin\varphi$, (mm/grad) [3].

Preliminary investigations showed that the breaking strength of iron doped bismuth microwires is more stable and higher as compared to the strength of pure bismuth microwires (Table 1). The breaking charge of microwires doped with iron concentration up to ~10 at % Fe in initial ingots is in the limits of 36 ÷ 103 g, for microwires doped with iron concentration up to ~20 at % in initial ingots it ranges within 70 ÷ 120 g, and for microwires of pure bismuth it is in the limits of 32 ÷ 85 g.

It should be mentioned that within the limits of small diameters of iron bismuth doped microwires there is a certain dispersion of experimental data, and the breaking strength increasing can be observed not only in the diameter decrease but also in the iron concentration dependence.

Table 1. The strength at breaking deformation of glass isolated bismuth microwires and iron doped bismuth microwires.

Bi				Bi + 10% Fe				Bi + 20% Fe			
d, μm	D, μm	P, g	σ, kg/mm^2	d, μm	D, μm	P, g	σ, kg/mm^2	d, μm	D, μm	P, g	σ, kg/mm^2
5.2	37.4	57.3	52.2	7.3	42.3	58.5	45.7	4.6	40.5	86.5	66.5
6.3	36.9	48.5	45.3	8.6	45.5	79.9	49.8	5.5	49.2	108.0	56.8
7.5	38.5	51.2	44.1	11.0	32.1	36.0	45.0	6.4	45.3	97.0	60.6
8.6	36.0	32.0	33.2	12.5	34.0	49.8	55.3	7.1	47.1	103.0	60.5
14.5	39.8	38.5	31.0	13.3	42.8	62.5	44.6	8.7	52.9	96.6	50.7
20.9	40.9	38.7	29.5	14.0	39.3	45.0	37.5	12.4	49.6	80.3	48.4
24.3	52.5	63.1	20.4	14.2	44.8	49.7	33.1	13.9	52.2	90.2	46.2
38.7	61.3	38.0	19.9	17.1	46.3	52.5	42.9	14.3	52.5	94.7	44.0
30.4	62.1	59.0	19.7	18.4	58.4	67.3	23.9	15.7	52.5	70.3	33.5
40.5	69.5	79.5	19.8	19.9	65.8	103.6	31.2	16.4	61.9	87.5	29.2
47.7	72.2	74.5	18.6	23.3	70.4	89.5	22.3	24.6	81.0	120.0	24.0
61.0	92.1	85.0	12.9					27.8	64.9	79.9	23.0

Table 2. The strength at flexing deformation of glass isolated bismuth microwires and iron doped bismuth microwires.

Bi				Bi + 10% Fe				Bi + 20% Fe			
d, μm	D, μm	r_{cr}, mm	D/d	d, μm	D, μm	r_{cr}, mm	D/d	d, μm	D, μm	r_{cr}, mm	D/d
4.7	26.3	0.388	5.6	7.3	42.3	0.563	5.8	4.6	40.5	0.453	8.8
10.8	25.4	0.406	2.4	8.0	35.8	0.491	4.5	5.6	49.2	0.472	8.8
11.2	24.6	0.384	2.2	8.7	45.5	0.494	5.2	7.6	43.6	0.458	5.7
11.2	25.6	0.432	2.3	11.0	32.1	0.425	2.9	8.8	63.5	0.591	7.2
11.3	24.0	0.332	2.1	12.5	34.0	0.516	2.7	12.5	56.7	0.501	4.5
29.8	55.3	0.482	1.8	13.3	42.8	0.382	3.2	13.9	61.3	0.509	4.4
49.1	75.6	0.434	1.5	14.0	39.3	0.463	2.8	14.2	54.0	0.564	3.8
53.1	81.8	0.634	1.5	14.2	44.8	0.381	3.2	16.4	81.0	0.641	4.9
56.6	85.3	0.590	1.5	17.1	46.3	0.580	2.7	18.9	55.5	0.641	2.9
61.0	90.2	0.571	1.5	17.1	55.1	0.401	3.2	20.5	64.2	0.603	3.1
				18.4	58.4	0.543	3.2	21.4	53.7	0.534	2.5
				20.4	59.1	0.503	2.9	27.8	65.0	0.591	2.3

The breaking strength of samples of microwires doped with iron concentration up to ~20 at % in initial ingots and the diameter range d = 27.8 ÷ 4.6 μm is bigger σ =33.0 ÷ 66.5 kg/mm^2 as compared to the breaking strength of pure bismuth σ =12.9 ÷ 45.3 kg/mm^2 and the diameters d = 61.0 ÷ 6.3 μm.

The study of flexion deformation was carried out too. The microwire flexing strength was determined for about 20 samples of the same diameters and a constant length of 0.5 mm. The obtained data show that though iron doped bismuth microwires have a high and stable hardness at breaking, their elasticity is less than the elasticity of microwires of pure bismuth. We can see from Table 2 that despite certain spread of experimental data, i.e., a decrease in internal diameters of microwires of pure bismuth, their elasticity increases; therefore, the flexion critical radius (r_{cr}) decreases. For iron doped bismuth microwires only the dispersion of results can be observed, even in the case of the same value of the internal diameter. For example, the values of flexion critical radius for samples with iron concentration of ~10 at % in initial ingots with the same internal diameter d = 17.1 μm are 0.580 mm and 0.401 mm for the external diameters D= 46.3 μm and D= 55.1 μm, respectively.

The flexion critical radius r_{cr} for samples of pure bismuth microwires is smaller than r_{cr} of samples of iron doped microwires. Possibly, that fact depends not only on high value of the ratio D/d for iron doped samples (8.9 ÷2.3) as compared with the ratio D/d of pure bismuth samples (3.2 ÷1.5) but also on structural defects of the impurities.

In fact, the results of microscopic studies of the breaking surface of iron doped bismuth samples with iron concentration up to ~20 at % Fe in initial ingots showed that in the majority of cases the microwire flexion breaking occurs in the places of iron globule incorporation.

The morphological optic study, in combination with chemical reagent attack, was carried out for revealing the morphology of the structural defects of investigated samples. In order to obtain smooth, pure, and homogeneous surfaces of samples for microscopic study, a new mechanical-chemical method of polishing was necessary, in which a fine emulsion of abrasives and aqueous salt solution was used. This mixture contributes to uniform polishing, and there appears the possibility of regulation and establishing of the low velocity of processing. It should be noted that the microwire final processing by polishing (for microscopic study) was also applied; it gave good results in the case of bunches prepared of studied microwires.

The morphological study carried out for the samples polished and cleaned by the obtained solution showed that the samples of bismuth microwire doped with a concentration up to ~20 at % Fe in initial ingots contain the minimal number of microdefects in comparison with the samples of bismuth doped with up to ~10, ~30, and ~40 at % Fe, which contain pores, microfissures, iron oxides, and granules. It was found that the longitudinal and transverse surfaces of the bismuth microwire doped with up to ~20 at % Fe in initial ingots are rather smooth and maintain close contact with glass isolation, and there is no chemical interaction between the microwire and glass. It was necessary to select a new chemical composition for microwire chemical treatment for making evident the iron amount, shape, and dimensions in the iron doped bismuth microwires, because the main methods for the bulk crystal processing, which comprise the nitric acid and ethylic alcohol, in the case of microwires do not give the satisfying results. The difficulties are connected with the fact that in the case of chemical etching of microwires, their surfaces do not become smooth, because the microwire centre and the surfaces that contact with glass isolation are not corroded homogeneously.

The microscopic study of samples exposed to chemical attack showed that the iron inclusions appear of a dark grey or black colour, have a globular shape, and are distributed nonhomogeneously against a light colour of bismuth. The iron amount estimated experimentally, using the microscopic images of the samples of bismuth microwires doped with a concentration up to ~20 at % of iron in initial ingots, is approximately 8%. It should be noted that the iron concentration calculus in the bismuth microwires doped with a concentration up to ~20 at % Fe in initial ingots was approximated. Complex methods, such as electronic and atomic microscopy and X-ray analysis, should be utilized for a veridical estimation.

The conclusion of this paper is that the basic mechanical characteristics of iron doped bismuth microwires were estimated, permitting their utilization in the field of ferromagnetic microsensing elements.

References

[1] C.L. Chien, F.Z. Zang, Kai Lui, and D.H. Reich, J. Appl. Phys., 87, 9, 4659, (2000).
[2] N.R. Berman, M.V. Giveliberg, and V.G. Ceban, Izvestiya AN MSSR, 3, 30, (1969).
[3] E.Ia. Badinter, N.R. Berman, and I.F. Drabenco, Litoi microprovod i ego svoistva, 317, 1973.